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Project 8.5

INCENDIARY EFFECTS OF ATOMIC BOMB TESTS ON BUILDING SECTIONS AT YUCCA FLAT

REPORT TO THE TEST DIRECTOR

by

H. D. Bruce

October 1952

[redacted]

Forest Products Laboratory
Forest Service, U. S. Department of Agriculture
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ABSTRACT

Sections simulating four types of frame building structures were exposed to TUMBLER Shots 3 and 4. The four types were: (1) cubicle room with furnishings, (2) wall-corner, (3) cornice-corner, and (4) roof. Sections 2 and 3 were exposed with and without a fine flash fuel. Douglas-fir springwood was charred at least slightly out to about 13,000 feet (radiant exposure 4.0 cal/cm^2) by Shot 3 and about 12,000 feet (radiant exposure 5.1 cal/cm^2) by Shot 4. Sustained burning, either as glowing or flaming, took place only in fine fuels. It was concluded that the flash of radiant energy from an atomic explosion will set sustained primary fire in fine fuel, but in general not in more massive fuels such as lumber and plywood. It is recommended that field study of primary fires on building structures be confined to fine fuels to ascertain the conditions under which they become ignited to self-sustaining fire and to such other shapes and materials as may be shown by laboratory experimentation to be a possible fuel for sustained primary fire.

ACKNOWLEDGEMENT

U. S. Forest Products Laboratory personnel engaged in this investigation are H. D. Bruce, Project Officer, T. R. Truax, Chief of Division of Wood Preservation, and John A. Scholten, Engineer.

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CHAPTER 1

TEST OBJECTIVE AND PROCEDURE

1.1 OBJECTIVE

This investigation is part of the thermal radiation program of the Armed Forces Special Weapons Project being conducted to ascertain the thermal effects of atomic weapons. The purpose of the investigation is to determine the probability of primary fires being started in urban areas of the United States by detonation of an atomic bomb. As an initial phase of this investigation specimens of common structural details of frame buildings were exposed to TUMBLER Shots 3 and 4 to obtain information on the vulnerability of wood buildings to primary ignition and sustained burning. Such information is important to the problem of civilian defense of urban areas, as well as to target damage prediction.

1.2 SPECIMENS

The four types of test specimens exposed to Shots 3 and 4 are shown in Figure A.1. They represented: (1) a cubicle room. (2) right-angle corner between walls, (3) right-angle corner with cornice, and (4) roof. Structure 1 included several combustible materials placed to receive radiant energy through a glass window. Structures 2 and 3 were exposed with and without excelsior at the base to serve as a "fuse" fuel. All wood was seasoned and all materials were new, except as otherwise stated.

Structural frame members of all specimens were two-by-fours of Douglas-fir. Interior walls and ceiling of the rooms were of 1/4-inch gypsum plaster board. All other flat surfaces were of five-ply 1/2-inch Douglas-fir, exterior-grade plywood. Window frames and sash were of ponderosa pine.

Roof sections were of wood shingles and asphalt shingles as are common on residences, and the built-up asphalt roof common on buildings with flat roof decks.

Asphalt shingles were of standard asphalt-felt composition, 210 pounds for 100 square feet, surfaced with slate granules colored a jade green. The shingles were new, but intentionally abraded to remove the slate granules and expose the asphalt over approximately 20 per cent of the exposed area.

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The wood shingles were of red cedar, No. 3 grade, darkened to a gray color with a stain of water soluble black dye. These shingles were new, but were thoroughly wet and dried several times after being laid to make them warp and curl as much as possible. Despite the wetting and drying only a small percentage of the shingles were badly curled at time of exposure.

The built-up roof was a typical asphalt-felt roof laid by a competent roofer with one course of 30-pound felt, three courses of 15-pound felt, and four moppings of asphalt for a total weight of 195 pounds per 100 square feet.

The wall-corner section simulated the V-corner that is found in nearly all residences. The cornice-corner section is the V-corner enclosed at the top by a roof, simulating the sheltered porch type of construction. These V-sections were chosen for test because of the resistance they would offer against the blowing away of flame from the pocket by the blast.

The room was constructed to represent a frame house. The 6-foot cubicle shape provided adequate strength and was large enough for conventional construction with standard framing members and covering materials. The front of the room contained a standard double-sash window to receive the radiation of the flash. One side wall contained a smaller window to relieve shock pressure and provide a through draft to the air blast.

For Shot 3, each room was furnished with a roughly constructed table and chair of yellow poplar, stained a dark walnut, and coated with two coats of a typical nitrocellulose furniture lacquer. The seat of the chair was cushioned with burlap upholstery padded with cotton waste (Fig. A.2). For curtains, white cheesecloth was draped in folds at the sides of the front window facing ground zero, and an oil-coated, muslin window shade of ecru color was hung at the top of the window exposing about 10 inches of its length. The arrangement was such that the shade, window curtain, table, chair back, and chair seat received direct illumination through the front window from the atomic flash.

For Shot 4, an old overstuffed chair covered with red or brown pile upholstery was added to the furnishings in three of the rooms (Fig. A.3), a white cotton tablecloth and newspapers were placed upon each table, and a piece of old quilt or sheeting was hung on the back of each wood chair to simulate clothing. A paper carton containing wastepaper to serve as a wastebasket was on the floor. Also a strip of old woolen rug was laid on the floor in back of the front window. Dark green, heavy rayon drapery was used in place of the white cheesecloth curtains used in Shot 3. The arrangement was such that the shade, draperies, overstuffed chair, and rug received radiation through the front window at the 7000-, 8000-, and 10,000-foot stations and shade,

draperies, rug, cotton tablecloth, and newspapers at the 9000- and 11,000-foot stations.

The excelsior used as a flash fuel at the base of some of the wall-corner and cornice-corner sections was a fine grade of spruce excelsior with strands of approximately 0.011 cm in thickness and 0.185 cm in width. It was light in color and reflected a high proportion of the radiation incident upon it.

1.3 LOCATION AND MOUNTING

The test structures were strongly constructed and mounted to resist demolition by the blast in order to show only the incediary effects of the flash.

In Shot 3, 31 construction specimens were placed at six stations, approximately 6000 to 16,000 feet from ground zero, as given in Table A.1.

In Shot 4, 51 construction sections were placed at nine stations, approximately 4000 to 13,000 feet from ground zero, as given in Table A.2.

All rooms, V-sections, and roof sections were oriented towards ground zero. The rooms and V-sections were set vertically; the roof sections were at an angle of 30° from the horizontal. Except at the 4000- and 5000-foot station all specimens were raised 4 feet off the ground to avoid sand blasting. Sandbag foundations were built under the rooms and V-specimens. Except at the 4000-foot station 2 inches of coarse gravel was spread in front of the test specimens to a distance of at least 50 feet toward ground zero in order to keep down as much as possible dust, sand, steam, and smoke at the time of the shot.

1.4 FABRIC PANEL

In addition to the construction specimens, a special panel was exposed normally to the radiation of Shot 4 at the 7000-foot station. This panel was divided into twelve 14- x 16-inch compartments in which six types of common household fabrics were placed for exposure to the flash with and without glass covering. The glass was single strength window glass. The fabrics were as follows:

a. Green rayon drapery, with air space behind.
b. Unbleached sheeting, one thickness, laid upon an underlayer of cotton cloth.
c. White cheesecloth, four layers, with air space behind.
d. Bright red cotton cloth, of looser weave than the sheeting, with air space behind.

[redacted]

e. Green frieze upholstery backed by cotton fiber upholstery padding.
f. Heavy, gray wool rug laid on plywood flooring.

1.5 MOISTURE CONTENT

Before Shot 3 the weather had been dry and warm, and without conditions conducive to dew for nine nights. Shot 4, on the other hand, was preceded by two days of rain and three nights of 100 per cent relative humidity and heavy dew. To estimate the moisture content of the wood of the building structures at the time of burst, samples of excelsior, Douglas-fir veneer, and cedar shingles were exposed to the atmosphere where they would not be influenced by the flash. Within 30 minutes after each burst the samples were collected and sealed for later analysis. The results of the analysis for moisture are given in Table A.3.

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CHAPTER 2

OBSERVATIONS AFTER SHOT 3

2.1 PHOTOGRAPHS AND TABLES

Documentary photos taken before and after Shot 3 are shown in Figures A.1 to A.13. The ground and slant distances for the exposure stations, the total thermal energy received at the stations and the time of arrival of the blast wave are given in Table 4. Tables 5, 6, and 7 summarize thermal effects observed in Shots 3 and 4.

2.2 ROOF SECTIONS

None of the roof sections caught on fire, and in no case was there loss of serviceability as a roof. The asphalt of the shingles and built-up roof sections melted and flowed at all distances tested. The cedar shingles were charred but did not burn. The depth of char in the wood shingles at 7000 feet was estimated to be a few tenths of a millimeter, but at 13,000 feet the surface was only slightly darkened.

2.3 WALL-CORNERS AND CORNICES

The springwood of the Douglas-fir plywood and lumber was affected where it was struck by the radiation of the atomic flash at all distances tested except at 16,000 feet. At 6000 feet the springwood was charred black and deep, but at 13,000 feet it was only slightly and superficially discolored in spotted patches. The more dense summerwood of the Douglas-fir was affected much less than the springwood and even at 6000 feet was only slightly darkened. The result was a black and yellow pattern (Fig. A.7) on the exposed surfaces of most of the Douglas-fir wood at 6000 to 10,000 feet from ground zero. Pieces of maple of high density attached to the structural supports at 6000 feet were blackened by the incident radiation, but not so deeply as the Douglas-fir springwood at the same stations.

The excelsior caught fire and burned at 7000 feet (Figs. A.6 and A.7) but not at 13,000 feet. At 10,000 feet the excelsior burned completely at the base of the cornice (Fig. A.12); at the base of the wall corner it was ignited but soon extinguished (Fig. A.11). Where the excelsior burned completely, the fire in the wood structure continued 2.3 and 3.5 minutes after the blast wave and burned deeply into the face of the panels and the under-side of the cornice to a depth of 1/16 to 1/8 inch before dying out.

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2.4 ROOMS

No sustained fires were set in the three rooms exposed to Shot 3. The pigmented cloth window shade of ecru color was ignited only at the 7000-foot station, but there is no evidence that the fire continued after the blast. The white cheesecloth window curtain was only very slightly scorched at 7000 feet, and unaffected by the thermal radiation at 10,000 and 13,000 feet. The heavy cotton cloth of exposed sandbags and an unbleached sheeting, used at some stations to protect the sandbags, were burned or charred out to 10,000 feet from ground zero and slightly scorched at 12,000 feet (Fig. A.5).

The chair and table furniture of yellow poplar wood was little damaged by the flash. At 7000 feet the burlap covering on the chair was blackened along the exposed edge and over a part of the seat, and the lacquer finish on the chair and table was whitened.

2.5 SPOT FIRE

At the 7000-foot station a piece of ignited sheeting was carried 30 to 40 feet, landing at the base of a sheet of plywood that had been blown from the back of a roof section. A spot fire resulted in which an appreciable area of the plywood was burned (Fig. A.13).

[redacted]

CHAPTER 3

OBSERVATIONS AFTER SHOT 4

3.1 PHOTOGRAPHS

Documentary photos taken before and after Shot 4 are shown in Figures A.14 to A.21.

3.2 ROOMS

None of the rooms nor any of their contents were set afire. The darker parts of newspapers inside the rooms were burned at 9000 feet (Fig. A.20) and discolored as far as 11,000 feet from ground zero. The pile fabric of the overstuffed chair upholstery was charred at 7000 feet (Fig. A.15) and slightly darkened at 10,000 feet. At 9000 feet the edges of the green rayon draperies were slightly browned, but at 7000 feet all the exposed area was deeply browned. The window shade showed discoloration only at 7000 feet.

3.3 EXCELSIOR

At 7000 feet the excelsior was ignited and consumed (Fig. A.18). At 8000 feet fine tips of the excelsior were charred and two spot fires were started, but the excelsior did not burn completely (Fig. A.19). At 10,000 feet only a few fine tips were discolored.

3.4 WALL-CORNERS AND CORNICES

At 6000, 7000, and 8000 feet the Douglas-fir plywood showed the characteristic black and yellow pattern due to charred springwood and almost unaffected summerwood, but very little pattern at 10,000 feet. Where the excelsior burned completely, the structure was deeply burned.

3.5 ROOFS

None of the roof sections were badly damaged either by radiation or blast. At 4000 and 5000 feet there was surface carbonization of the cedar shingles to a depth of a few tenths of a millimeter, but progressively less at greater distances. At 4000 and 5000 feet the asphalt composition shingles became hot enough to discolor and lose much of the bright green color, but would still be serviceable as a roof. There was evidence that the asphalt of the built-up roofing melted at all distances out to 10,000 feet.

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3.6 SCRAP PILES

At 7000 and 10,000 feet there were scrap piles of waste plywood and lumber. The one at 10,000 feet also contained paper, excelsior, and cartons. At 7000 feet there was some charring of the wood but no evidence of burning. At 10,000 feet the excelsior and the paper caught fire and burned appreciably at three or four spots, depositing soot on pieces of wallboard, but the fires soon went out (Fig. A.21).

3.7 FABRICS

The panel of fabrics at 7000 feet, half directly exposed and half exposed under glass, gave various results (Fig. A.16). In general the glass offered a protective screening that reduced thermal effects on the fabrics beneath. This was particularly evident with the green rayon drapery, the white cheesecloth, and the red cotton cloth. Protective screening by the glass was not very evident with the unbleached sheeting, the frieze upholstery, or the wool rug. All fabrics under glass or exposed directly were badly charred and two of the fabrics directly exposed -- the green rayon and the red cloth -- were completely consumed.

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CHAPTER 4

DISCUSSION AND CONCLUSIONS

4.1 BLAST DAMAGE

From observations of physical damage done by the atomic blasts of TUMBLER Shots 3 and 4 to the building structures exposed by Project 8.5, it is probable that typical frame dwelling houses, directly struck by the shock wave, would be practically demolished within a circle of about 7000 feet radius by a bomb of Shot 3 strength or within a circle of about 5000 feet radius by a bomb of Shot 4 strength. Within this "circle of demolition" primary fires, ignited by thermal radiation from the bomb would assist secondary fires caused by overturned stoves, broken gas lines, and the like, in building up a general conflagration, but would be of secondary importance to the bomb blast as an agent of destruction.

4.2 THERMAL EFFECTS ON LUMBER AND PLYWOOD

From the results of this field study it was evident that an intense but brief flash of thermal radiation from an atomic bomb may singe surfaces of sound lumber and plywood and even carbonize the surfaces to a depth of several tenths of a millimeter but will not set the wood afire for any appreciable period beyond possibly a transient flash. It is concluded therefore that, at least beyond the circle of demolition, primary fires are not, in general, ignited in massive wood (massive, as distinguished from finely divided wood such as excelsior and paper), by the momentary thermal radiation from an atomic bomb.

4.3 THERMAL EFFECTS ON FINE FUEL

The only primary fires ignited in these tests and sustained for more than a brief moment were in fabrics, excelsior, paper, and punky wood. The fabric and excelsior fires were intense enough to spread to adjacent wood structures. The paper and punky wood fires might have started other fires under more favorable moisture conditions. Primary fires, therefore, can be started by strong momentary thermal radiation in fine combustible material, such as fabrics, excelsior, paper, and punky wood, burning either as glowing or flaming combustion and continuing to burn after the shock wave. These primary fires may in turn ignite wood structures. Whether these fires in wood structures die out with the primary fire in the fine fuel, or whether they are self sustaining, depends on the physical properties of the wood, its moisture content, and the rate of flow of heat to the wood surface by radiation

[redacted] [redacted]

and convection, in accordance with physical laws of fire.

4.4 EFFECT OF MOISTURE CONTENT

There was some evidence (Table A.7) that the higher moisture content of the combustible substances at Shot 4 decreased to some extent the charring and igniting effects of the incident radiation. In particular, drier excelsior at Shot 4 would probably have burned more readily in those cases where the excelsior tips were singed off and would probably have burned completely where spot fires were ignited.

Of even greater importance than the effect of moisture upon the ignition of primary fire appeared to be the effect of moisture on the extension of the primary fires into other combustible fuels. There is little doubt that the several primary fires started by Shot 4 would have burned the adjacent structures and materials more severely but for the high moisture content on the morning of the shot.

4.5 EXTINGUISHING EFFECT OF BLAST

The blast that follows an atomic flash has a pronounced tendency to extinguish flame. This was illustrated by the spot fires started in the trash pile at the 10,000-foot station by Shot 4, which would most probably have resulted in a "bonfire" if the flames of the spot fires had not been blown out by the blast. There is evidence that glow is not extinguished by blast as readily as flame. Cotton and rayon fabrics and punky wood were relatively easy to ignite and tended to continue to glow despite the blast of a shock wave. They are, therefore, serious potential firebrands. Also it is probably that the extinguishing effects of the blast will vary with the form and the compactness of the burning substance. Thus flame may be blown off a smooth wood surface but into a mass of excelsior.

[redacted]

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

Cubicle-rooms with furnishings, and wall-corner, cornice-corner, and roof sections were exposed to Shots 3 and 4 at distances from about 4000 to 16,000 feet from ground zero.

Springwood Douglas-fir surfaces were singed by incident thermal radiation as low as 2.7 cal/cm^2, but were not ignited to sustained primary fire by energies as high as 23.6 cal/cm^2.

Asphalt surfaces were melted by incident thermal radiation as low as 2.8 cal/cm^2, but were not ignited to sustained primary fire by energies as high as 23.6 cal/cm^2.

Primary fires were ignited in fine combustible excelsior, fabrics, paper, and punky wood. The fire in the excelsior was ignited by radiant energies as low as 6.7 cal/cm^2.

The following more important conclusions were drawn:

a. Sustained primary fires are not set in sound massive wood, at least beyond the circle of extensive demolition, by the brief flash of radiant energy from an atomic bomb of thermal energies of Shots 3 and 4.

b. Primary fires may be set in fine combustible matter by the atomic bomb flash.

c. Primary fire flame in fine combustible matter may or may not be blown out by the shock wave blast.

d. Primary fire glow in fine combustible matter resists extinction by the shock wave blast.

e. Fires in wood structures may be started by primary fire in fine combustible fuel.

f. The duration of fires in building structures started by primary fires in fine fuels ignited by the atomic flash depends on physical laws of fire with little dependence on the radiation from the bomb.

5.2 RECOMMENDATIONS

At present too little is known about the conditions under which sustained primary fires are ignited by an atomic flash, the nature of the combustion (whether flame or glow) and the probability of the fire being extinguished by the atomic blast. Accordingly it is

[redacted]

recommended:

(1) That laboratory experimentation be conducted to ascertain the conditions (including dimensions, surface texture, quantity, subdivision, compactness, moisture content, and radiant energy) under which materials commonly found in cities and towns are ignited to sustained burning by intense but brief radiation as from an atomic bomb.

(2) That the conditions be ascertained by laboratory experimentation under which primary fires ignited by radiation are extinguished by a blast similar to that from an atomic explosion.

(3) That field experimentation include spot checks of those materials or constructions that have been found in the laboratory to be ignited by thermal energies of less than 2[illegible] cal/cm^2 which sustain combustion either by glowing or flaming, and which resist extinction of the burning by a shock blast of air.

(4) That, following the laboratory and field experimentation, a method of surveying urban areas be devised by which the frequency of occurrence of substances ignitable to sustained primary fire could be ascertained for an estimate of the probable number of fires that would be set per square mile by an atomic detonation.

(5) That recommendations be made from the results of the laboratory and field experiments as to measures that should be taken to reduce the probability of general conflagration in urban areas of the United States in the event of an atomic weapon attack.

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APPENDIX A

ILLUSTRATIONS AND TABLES

Fig. A.1. The Several Types of Test Structure (room; wall-corner and cornice-corner with and without excelsior; three roof sections) installed for TUMBLER Shots 3 and 4.

[redacted]

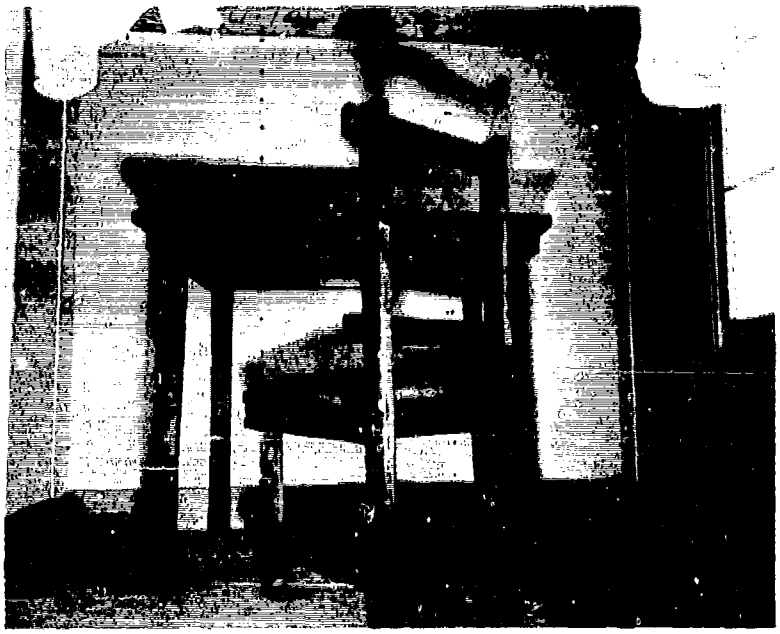

Fig. A.2. Hardwood Table and Chair with Padded Seat of the Type Placed in Each Room Exposed to Shot 3.

Fig. A.3. Red Pile Overstuffed Chair Exposed to Shot 4 in Room at 10,000-ft Station.

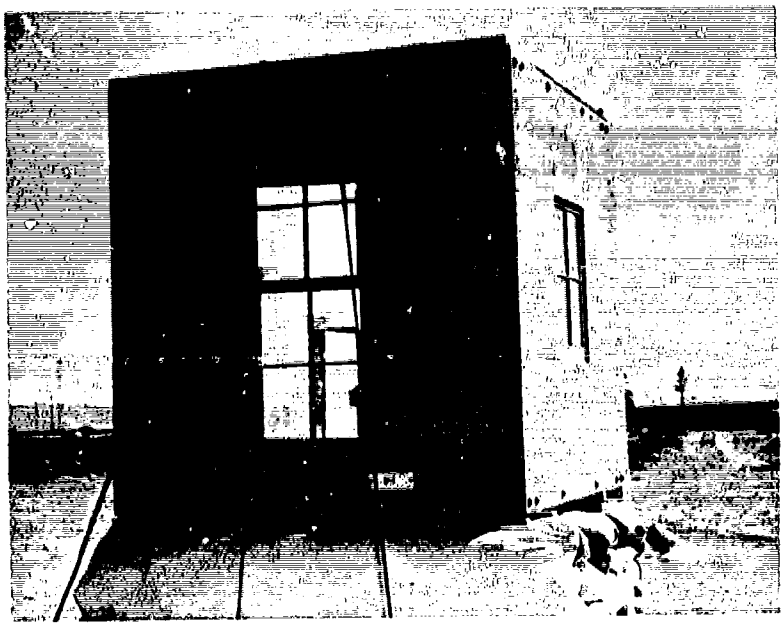

Fig. A.4. Room at 7000-ft Station Before Shot 3.

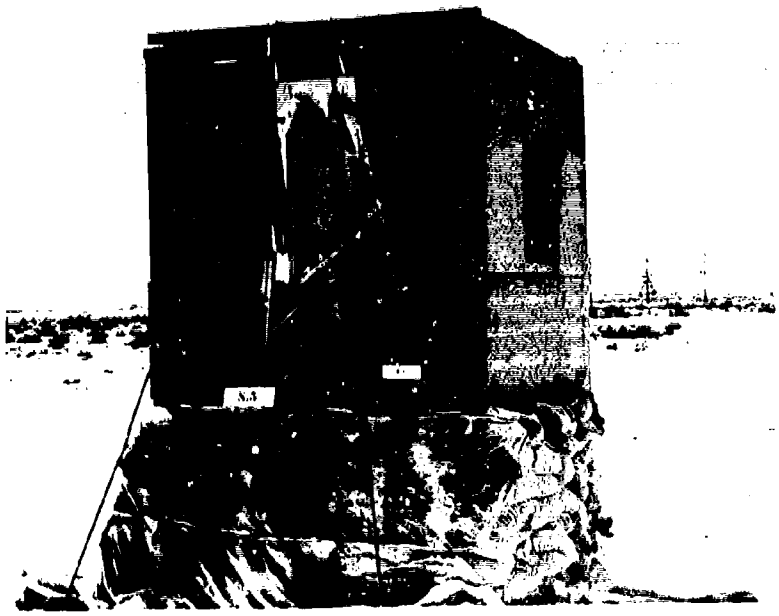

Fig. A.5. Room at 7000-ft Station After Shot 3. Shade, front wall, and sheeting covering sandbags charred. No sustained burning.

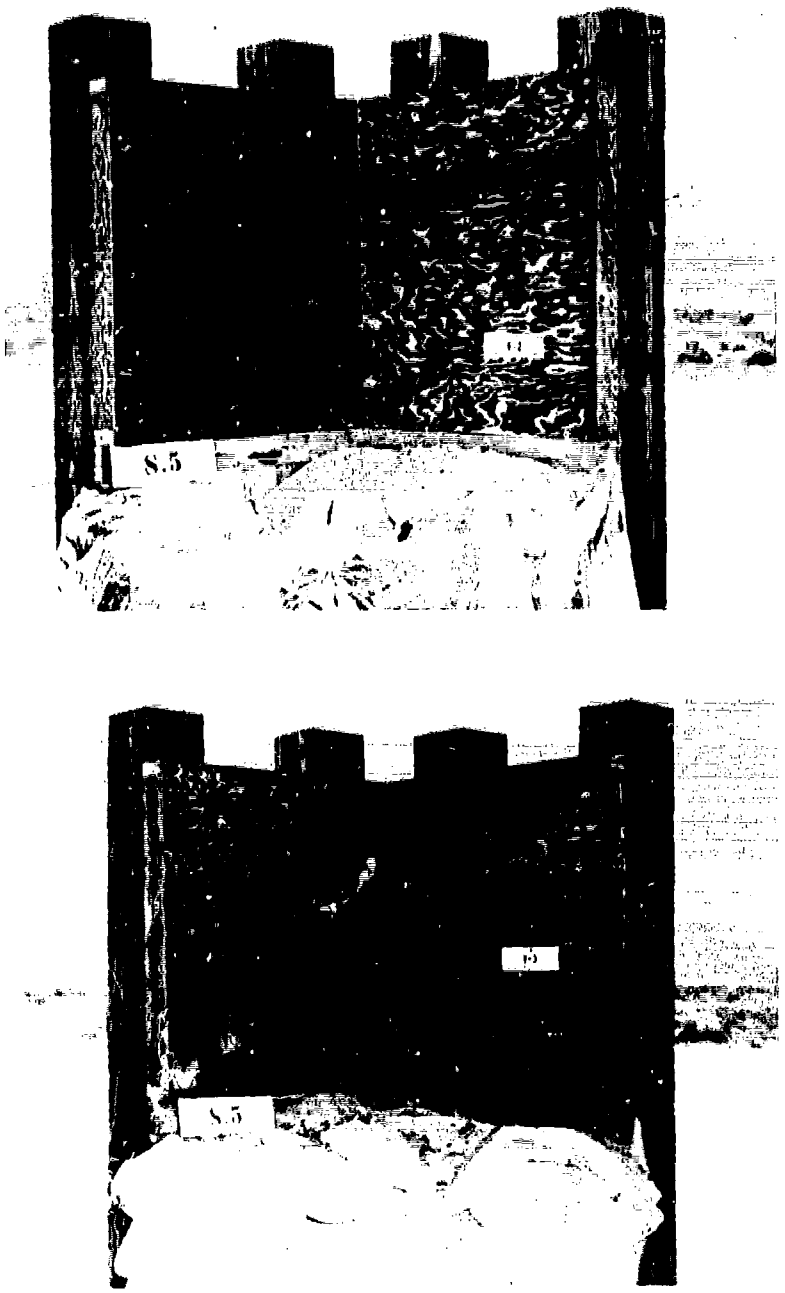

Fig. A.6. Wall-corner Sections at 7000-ft with (bottom) and without (top) Excelsior, After Shot 3. Douglas-fir plywood and posts singed. Excelsior burned, charring the plywood deeply.

Fig. A.7. Cornice-corner Sections at 7000-ft with (bottom) and without (top) Excelsior, After Shot 3. Plywood and posts singed. Plywood deeply burned by fire in excelsior.

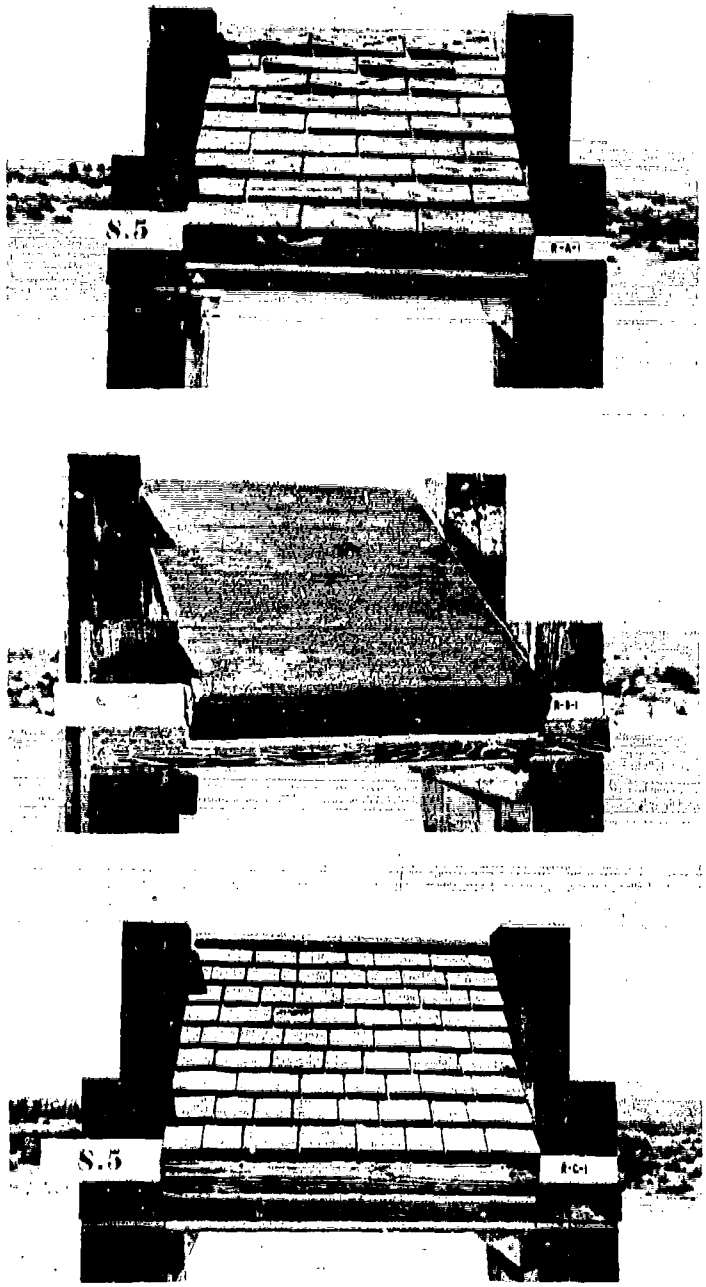

Fig. A.8. Asphalt Shingle, Built-up Asphalt, and Cedar Shingle Roof Sections at 7000-ft after Shot 3. Asphalt shingles bent; wood shingles blackened; surface asphalt melted and flamed.

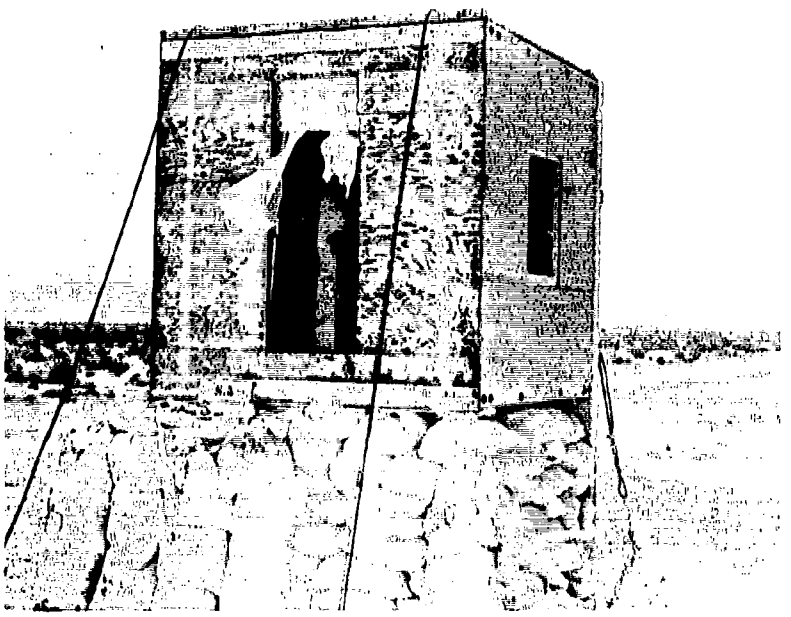

Fig. A.9. Room at 10,000-ft After Shot 3. Front wall singed. Sheeting covering sandbags burned away.

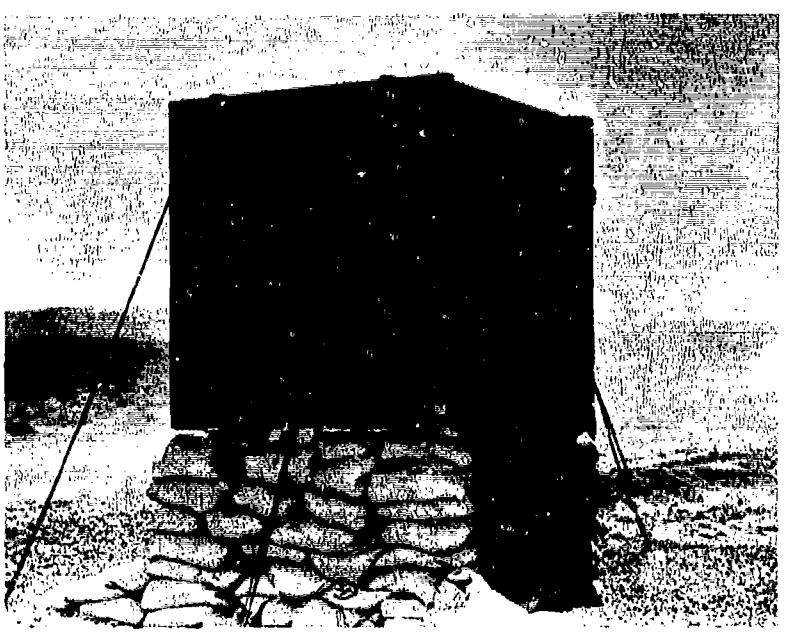

Fig. A.10. Room at 13,000-ft After Shot 3. No thermal damage.

Fig. A.11. Wall-corner Sections at 10,000-ft After Shot 3. Two spot fires of short duration in the excelsior.

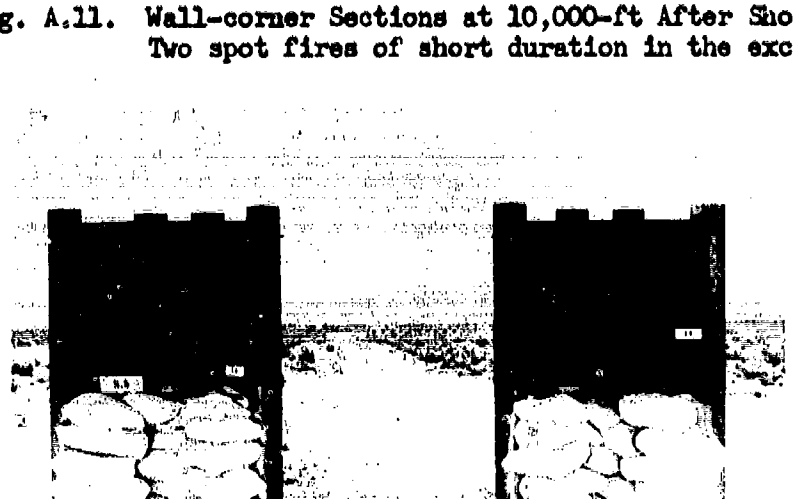

Fig. A.12. Cornice-corner Sections Exposed with and without Excelsior to Shot 3 at 10,000-ft Station. Plywood on right deeply burned by fire in excelsior.

Fig. A.13. Spot Fire at 7000-ft Station in a Sheet of Douglas-fir Plywood Set Ablaze by a Firebrand of Sheeting Ignited by Shot 3.

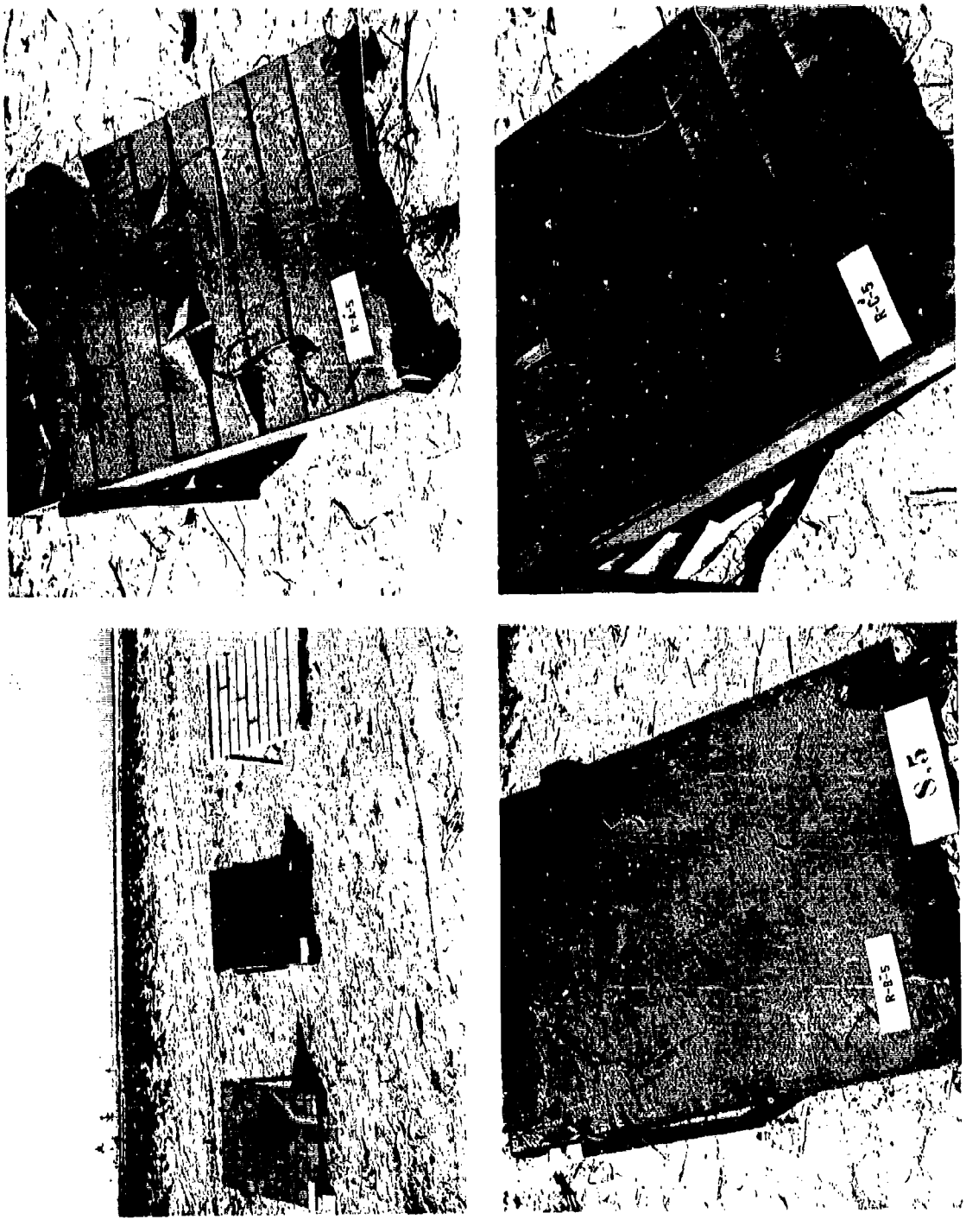

Fig. A.14. Three Roof Sections at 4000-ft, Before (top left) and After Exposure to Shot 4.

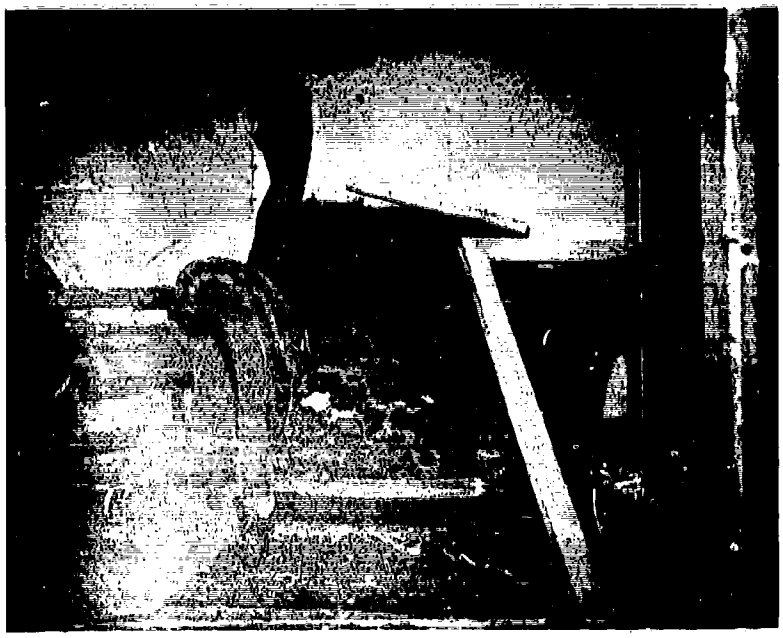

Fig. A.15. Interior of Room at 7000-ft After Shot 4. Sash, shade, and drapery blown in; upholstery torn by flying glass; part of chair upholstery pile darkended by carbonization.

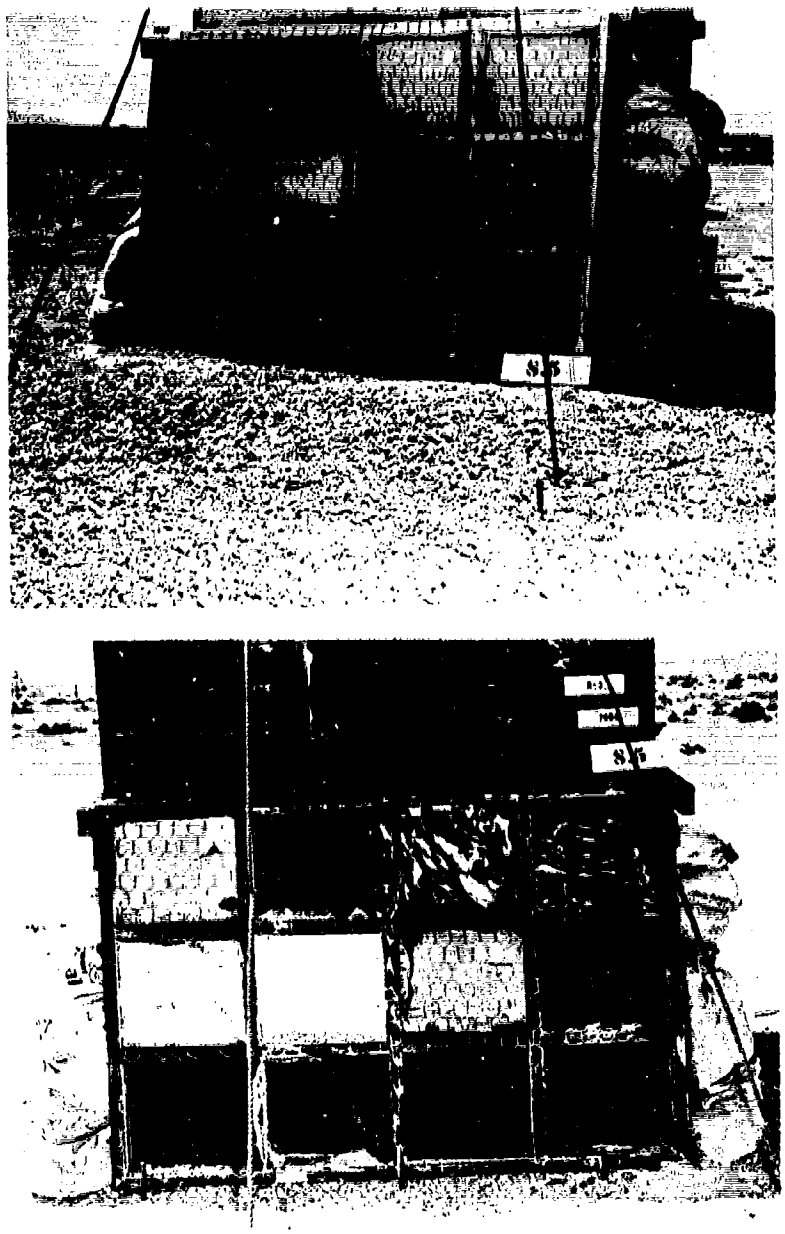

Fig. A.16. Panel of Fabrics at 7000-ft, Before and After Shot 4. Wood singed; glass shattered; rayon drapery burned; cotton sheeting burned; cheesecloth slightly browned; red cotton cloth burned; frieze charred; wool rug fused and charred.

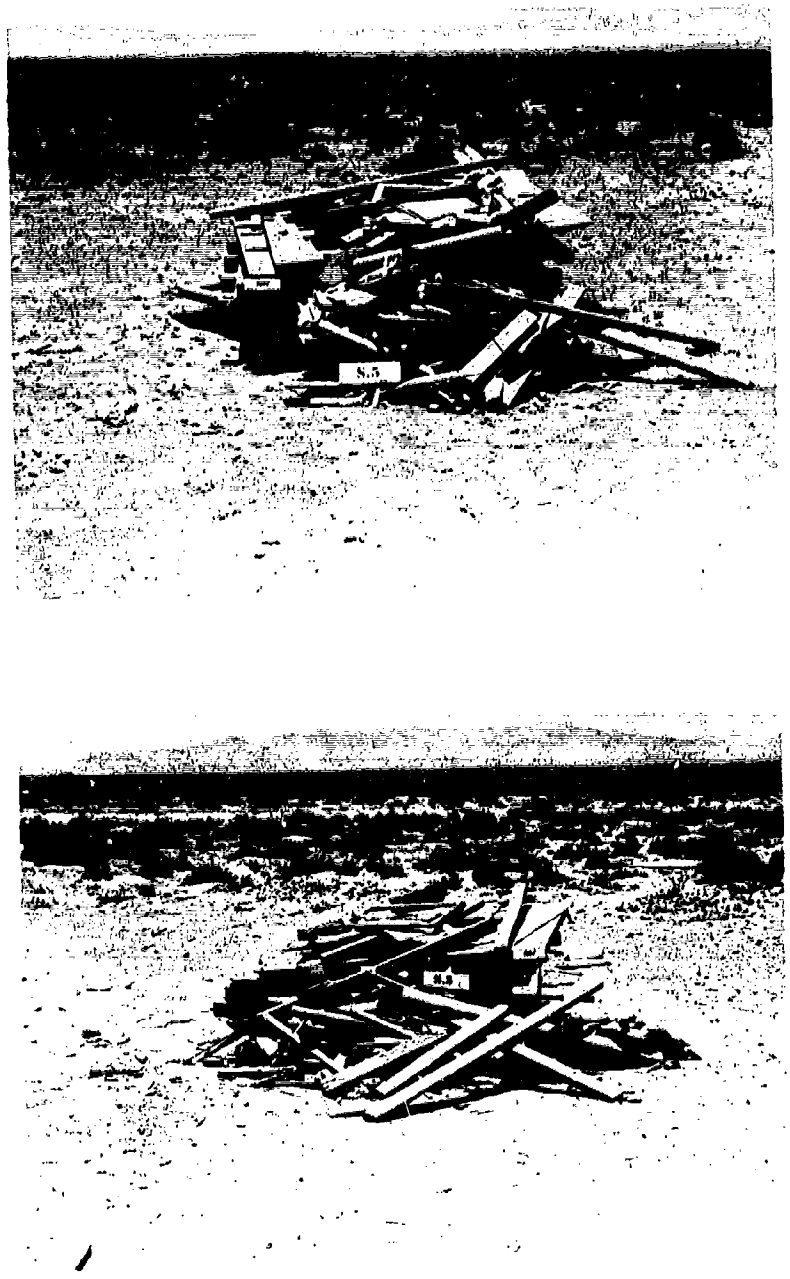

Fig. A.17. Scrap Pile of Wood at 7000-ft Station Before (top) and After (bottom) Shot 4. Exposed wood singed; pile disarranged; no burning.

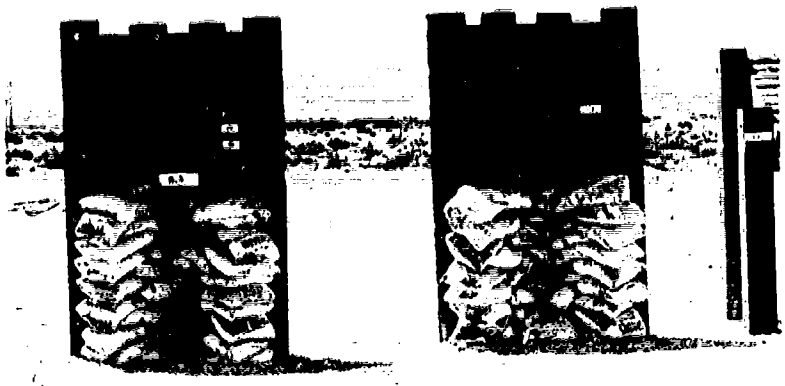

Fig. A.18. Cornice-corner at 7000-ft After Shot 4. Plywood singed; sandbags charred in spots; excelsior set afire.

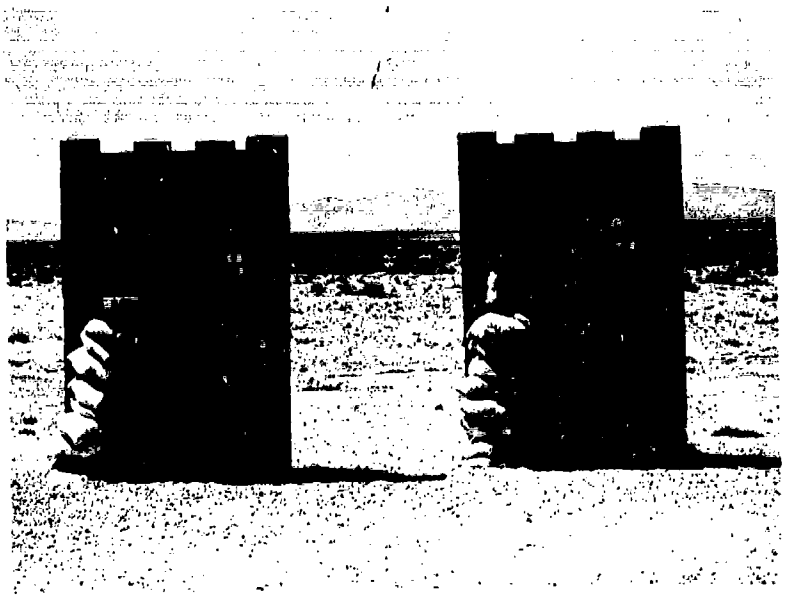

Fig. A.19. Cornice-corner at 8000-ft After Shot 4. Plywood singed; excelsior tips burned; two brief spot fires in the excelsior.

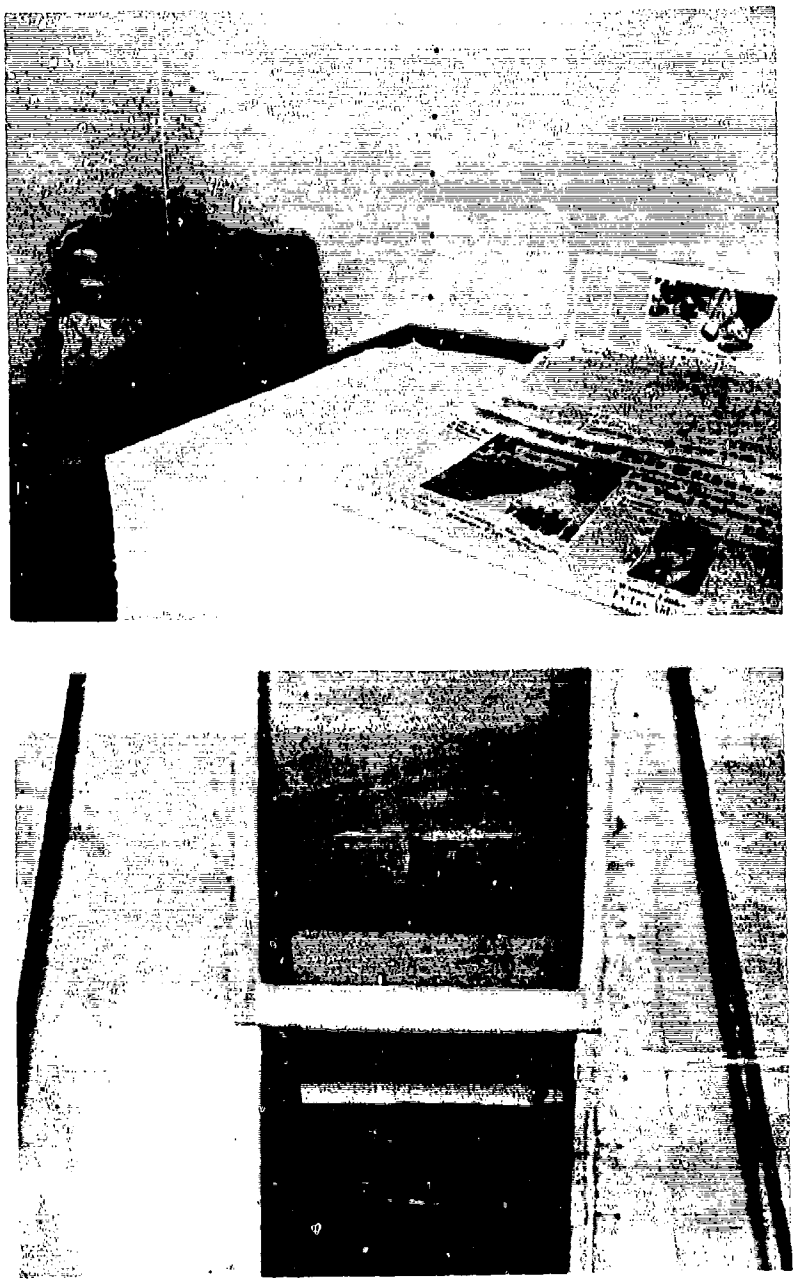

Fig. A.20. Interior of Room at 9000-ft Before and After Shot 4. Newspaper against far wall (bottom picture) partly burned.

Fig. A.21. Scrap Pile at 10,000-ft Before (top left) and After Shot 4. Pile disarranged but not set afire. Soot on under side of plaster board from spot fire in excelsior or brush (bottom left). Pencil (bottom right) points to partly burned newspaper.

TABLE A.1

Disposition of Test Specimens in TUMBLER Shot 3

Station	Room	Wall-corner	Cornice-corner	Roof		
				Asphalt shingle	Asphalt built-up	Cedar shingle
6000'		X	X			
7000'	X	X X*	X X*	X	X	X
8000'				X	X	X
10,000'	X	X X*	X X*	X	X	X
13,000'	X	X X*	X X*	X	X	X
16,000'		X*	X*			

*Excelsior, 1-1/4 pounds, was at the base of these specimens as a "fuse" fuel.

TABLE A.2

Disposition of Test Sections in TUMBLER Shot 4

Station	Room	Wall-corner	Cornice-corner	Roof		
				Asphalt shingle	Asphalt built-up	Cedar shingle
4000'				X	X	X
5000'				X	X	X
6000'		X	X	X	X	X
7000'	X	X X*	X X*	X	X	X
8000'	X	X X*	X X*	X	X	X
9000'	X			X	X	X
10,000'	X	X X*	X X*	X	X	X
11,000'	X					
12,000'		X X*	X X*			
13,000'		X X*	X X*	X	X	X

*Excelsior, 1-1/4 pounds, was at the base of these specimens as a "fuse" fuel.

[redacted]

TABLE A.3

Moisture Content Values of Wood Samples

Sample of material	Moisture content values*	
	Shot 3	Shot 4
	Percent	Percent
Veneer, inside test room	--	12.1
Veneer, outside	6.2	11.9
Shingles, outside	6.6	11.4
Excelsior, outside	5.3	12.2

*Expressed as percentage of weight dried at 100° C.

[redacted] [redacted]

TABLE A.4

Distances, Thermal Radiation and Blast Arrival for the Exposure Stations in TUMBLER Shots 3 and 4

Exposure Station	Ground Distance	Slant Distance	Total Thermal Radiation[1]	Blast Arrival Time
	Feet	Feet	Calories/cm^2	Seconds
TUMBLER Shot 3				
6000'	5964	6886	16.3	4.56
7000'	6982	7784	12.7	5.32
8000'	7974	8685	10.1	6.08
10,000'	9964	10,541	6.7	7.67
13,000'	12,953	13,402	4.0	10.08
16,000'	15,947	16,313	2.7	12.51
TUMBLER Shot 4				
4000'	3922	4065	33.5	2.26
5000'	4910	5017	21.4	3.02
6000'	5901	5991	14.9	3.78
7000'	6918	6995	10.8	4.62
8000'	7911	7978	8.1	5.44
9000'	8905	8965	6.4	6.31
10,000'	9901	9955	5.1	7.14
11,000'	10,897	10,946	4.2	8.00
12,000'	11,894	11,939	3.5	8.83
13,000'	12,891	12,933	3.0	9.68

[1] Calculated from revised total thermal radiation curves for Operation K/U issued October 6, 1952.

TABLE A.5

Thermal Effects of TUMBLER Shot 3

Station	Normal thermal energy	Incident thermal energy[1]	Incendiary effect
	Cal/cm^2	Cal/cm^2	
6000'	16.3	10.0-14.1	Douglas-fir lumber and plywood singed to yellow-black pattern. No sustained flame or glow.
		15.7	Maple blackened.
7000'	12.7	8.1-11.4	Douglas-fir singed to yellow-black pattern.
		--	Excelsior burned completely; sustained fire on both V-sections.
		10.6	Asphalt melted; no evidence of flame. Cedar shingles blackened.
		--	Shade ignited, but fire extinguished. Cheesecloth curtain slightly scorched. Furniture lacquer whitened. Furniture wood undamaged. Burlap seat blackened.
		--	Unbleached muslin charred through; sustained flame or glow.
		--	Sandbag canvas blackened.
8000'	10.1	9.3	Douglas-fir lumber singed yellow-black.
		8.1	Asphalt melted. Cedar shingles blackened. No sustained flame or glow.

[1] Normal energy x cosine of angle of incidence.

[redacted]

TABLE A.5 (Continued)

Thermal Effects of TUMBLER Shot 3

Station	Normal thermal energy	Incident thermal energy	Incendiary effect
	Cal/cm^2	Cal/cm^2	
10,000'	6.7	6.3	Douglas-fir wood singed yellow-brown.
		--	Excelsior burned completely at cornice; sustained burning.
			Excelsior ignited at wall-corner; flame not sustained.
		5.1	Asphalt melted. Cedar shingles darkened.
		--	Shade not darkened. Cheesecloth curtain not darkened. Furniture lacquer whitened in spots.
			Table and chair wood undiscolored.
			Burlap seat darkened.
		--	Unbleached muslin charred through; sustained glow.
		--	Sandbag canvas darkened in spots.
13,000'	4.0	3.9	Douglas-fir springwood darkened.
		2.7	Douglas-fir springwood darkened in spots.
		--	Excelsior not charred.
		2.8	Asphalt melted. Cedar shingles slightly darkened.
		--	Shade not darkened. Cheesecloth curtain not darkened. Furniture lacquer undiscolored. Burlap seat not darkened.
16,000'	2.7	1.9	No thermal effects.

[redacted]

TABLE A.6

Thermal Effects of TUMBLER Shot 4

Station	Normal thermal energy	Incident thermal energy[1]	Incendiary effect
	Cal/cm^2	Cal/cm^2	
4000'	33.5	23.6	Both spring and summerwood of Douglas-fir blackened; springwood, deeply.
		23.6	Asphalt deeply melted; no evidence of flame. Green slate granules discolored gray. Asphalt shingles fused together. Cedar shingles deeply charred. Deep carbonization from sustained glow in punky wood of shingle.
5000'	21.4	14.3	Douglas-fir springwood charred deeply, summerwood darkened.
		14.3	Asphalt deeply melted. Green slate granules badly faded, or discolored to gray. Asphalt shingles fused together. Cedar shingles blackened.
6000'	14.9	10.4	Douglas-fir singed to black-brown pattern. Springwood deeply charred.
		9.6	Asphalt deeply melted. Green slate granules undiscolored. Asphalt shingles fused together. Cedar shingles blackened.
		--	Sandbag canvas charred.

[1] Normal energy x cosine of angle of incidence.

[redacted]

TABLE A.6 (Continued)

Thermal Effects of TUMBLER Shot 4

Station	Normal thermal energy	Incident thermal energy	Incendiary effect
	Cal/cm^2	Cal/cm^2	
7000'	10.8	7.6	Douglas-fir singed to yellow-black pattern.
		--	Excelsior burned completely; sustained burning on both V-sections with excelsior, through face ply.
		6.7	Asphalt melted. Asphalt shingles not fused together. Cedar shingles blackened.
		--	Shade darkened.
		--	Wood of scrap pile charred to a yellow-black pattern; no evidence of flaming or glowing.
7000'	10.8	--	Green drapery in room browned; evidences of temporary glowing. Chair furniture finish turned dark brown. Chair wood not discolored. Pile upholstery partly carbonized.
		--	Sandbag canvas charred in spots.
	10.8	10.8	Green rayon drapery, directly exposed -- completely burned, charring batten strips.
		--	Same, exposed behind glass -- charred dark brown.
7000'	10.8	10.8	Unbleached sheeting, directly exposed -- top layer completely burned, second layer charred in spots, third layer discolored in spots.
		--	Same, exposed behind glass -- similar to sheeting directly exposed.

[redacted]

[redacted]

TABLE A.6 (Continued)

Thermal Effects of TUMBLER Shot 4

Station	Normal thermal energy	Incident thermal energy	Incendiary effect
	Cal/cm^2	Cal/cm^2	
7000'	10.8	10.8	White cheesecloth, directly exposed -- about 15 percent of area browned.
		--	Same, exposed behind glass -- slight browning of edges only.
	10.8	10.8	Red cotton cloth, directly exposed -- both layers almost completely burned away.
		--	Same, exposed under glass -- top layer severely charred, under layer almost undiscolored.
	10.8	10.8	Green frieze upholstery, directly exposed -- nap severely charred with green color gone, base fabric discolored.
		--	Same, exposed under glass -- nap severely charred with green color gone, base fabric slightly discolored.
	10.8	10.8	Gray wool rug, directly exposed -- heavy nap charred, fused, and discolored brown.
		--	Same, exposed behind glass -- similar to wool rug, directly exposed.
8000'	8.1	5.7-8.0	Douglas-fir singed to yellow-black pattern.
		--	Most of excelsior unchanged; flaming or glowing excelsior tips fell on sandbags charring the

[redacted]

TABLE A.6 (Continued)

Thermal Effects of TUMBLER Shot 4

Station	Normal thermal energy	Incident thermal energy	Incendiary effect
	Cal/cm^2	Cal/cm^2	
			canvas; two small spot fires in the excelsior adjacent to the cornice-corner; no sustained burning.
8000'	8.1	4.9	Asphalt melted. Cedar shingles blackened.
		--	Shade not discolored. Green drapery discolored brown. Chair front upholstery pile and pillow darkened. Wood of upholstered chair unaffected.
9000'	6.4	6.4	Douglas-fir wood singed brown-yellow in spotted pattern.
		3.8	Asphalt melted. Cedar shingles slightly darkened.
		--	Shade not discolored. Green drapery browned at edges. Sheeting tablecloth not discolored. Black print of newspaper charred through one sheet and into next.
10,000'	5.1	3.6-5.1	Springwood of the Douglas-fir only slightly and occasionally darkened; singed pattern not conspicuous.
		--	Excelsior unburned; a few tips discolored brown.
		3.0	Asphalt slightly melted. Cedar shingles barely discolored.

[redacted]

TABLE A.6 (Continued)

Thermal Effects of TUMBLER Shot 4

Station	Normal thermal energy	Incident thermal energy	Incendiary effect
	Cal/cm^2	Cal/cm^2	
		--	Shade not discolored. Green drapery not discolored. Pile of chair upholstery very slightly darkened.
		--	Spot fires started in scrap pile, where newspaper, black photo paper, and excelsior ignited, charring paper carton edges and depositing soot on gypsum board; but spot fires were of short duration.
11,000'	4.2	--	Parts of newspaper browned. No other thermal effects.
12,000'	3.5	--	No thermal effects.
13,000'	3.0	1.7	No evidence of asphalt melting.
		--	No thermal effects.

[redacted]

TABLE A.7

Thermal Effects on Various Substances by Radiation from TUMBLER Shots 3 and 4

Substance	Energy[1] causing effect calories per sq. cm.				Thermal effect observed
	Normal		Incident		
	Shot 3	Shot 4	Shot 3	Shot 4	
Douglas-fir summerwood	.....	8.1	.....	8.0	No effect
	12.7	10.8	8.1	7.6	Slight darkening
	.....	4.9	.....	10.4	Browned
	.....	33.5	.....	23.6	Blackening
Douglas-fir springwood	2.7	4.2	1.9	4.2	No effect
	4.0	5.1	2.7	5.1	Slight darkening
	6.7	6.4	6.3	6.4	Browning
	10.1	10.8	9.3	7.6	Blackening
Excelsior	4.0	3.5	.....	.....	Not discolored
	.....	5.1	.....	.....	Tips browned
	6.7	8.1	.....	.....	Spot fires
	6.7	10.8	.....	.....	Sustained fire
Asphalt	4.0	5.1	2.8	3.0	Slight melting
	12.7	14.9	10.6	9.6	Deep melting
Cedar shingles	4.0	5.1	2.8	3.0	Slight discoloration
	12.7	14.9	10.6	9.6	Blackened
	.....	3.5	.....	23.6	Deeply charred
Ecru window shade (behind glass)	6.7	8.1	.....	.....	Not discolored
	.....	10.8	.....	.....	Browned
	12.7	.....	.....	.....	Ignited
White cheesecloth	.....	10.8	.....	10.8	Browned

[redacted]

TABLE A.7 (Continued)

Thermal Effects on Various Substances by Radiation from TUMBLER Shots 3 and 4

Substance	Energy[1] causing effect calories per sq. cm.				Thermal effect observed
	Normal		Incident		
	Shot 3	Shot 4	Shot 3	Shot 4	
White cheesecloth (behind glass)	6.7	.....	.....	.....	Not discolored
	12.7	10.8	.....	.....	Edges browned
Green rayon drapery	.....	10.8	.....	10.8	Burned
Green rayon drapery (behind glass)	.....	5.1	.....	.....	Not discolored
	.....	6.4	.....	.....	Edges browned
	.....	8.1	.....	.....	Browned
	.....	10.8	.....	.....	Charred dark brown
Furniture lacquer (behind glass)	4.0	.....	.....	.....	Not discolored
	6.7	.....	.....	.....	Whitened
	.....	10.8	.....	.....	Browned
Red pile upholstery (behind glass)	.....	5.1	.....	.....	Slight discoloration
	.....	8.1	.....	.....	Darkened
	.....	10.8	.....	.....	Blackened
Burlap chair seat (behind glass)	4.0	.....	.....	.....	Not discolored
	6.7	.....	.....	.....	Browned
	12.7	.....	.....	.....	Blackened
Unbleached muslin sheeting	6.7	.....	.....	.....	Charred through
	.....	10.8	.....	10.8	Burned
Unbleached muslin sheeting (behind glass)	.....	6.4	.....	.....	Not discolored
	.....	10.8	.....	.....	Burned
Newspaper (behind glass)	.....	4.2	.....	.....	Browned
	.....	6.4	.....	.....	Charred through

[1] These values are not necessarily the minimum or maximum intensities that would produce the observed thermal effects.

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Clothing Supply Office, USN Supply Activities, New York, 3d Ave. & 29th St., Brooklyn 32, N. Y. ATTN: R&D Div.	148

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Special Asst. to Chief of Staff, Headquarters, USAF, Rm 5E1019, Pentagon, Washington 25, D. C.	149
Asst. for Atomic Energy, Headquarters, USAF, Washington 25, D. C. ATTN: DCS/O	150
Asst. for Development Planning, Headquarters, USAF, Washington 25, D. C.	151-152
Director of Operations, Headquarters, USAF, Washington 25, D. C.	153-155
Director of Plans, Headquarters, USAF, Washington 25, D. C. ATTN: War Plans Division	155
Directorate of Requirements, Headquarters, USAF, Washington 25, D. C. ATTN: AFDRQ-SA/M	156
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Directorate of Intelligence, Headquarters, USAF, Washington 25, D. C.	158-159
The Surgeon General, Headquarters, USAF, Washington 25, D. C.	160-161
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Commanding General, Alaskan Air Command, APO 942, c/o PM, Seattle, Wash.	164
Commanding General, Northeast Air Command, APO 862, c/o PM, New York, N. Y.	165
Commanding General, Strategic Air Command, Offutt AFB, Omaha, Neb. ATTN: Chief, Operations Analysis	166
Commanding General, Tactical Air Command, Langley AFB, Va. ATTN: Document Security Branch	167-169
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Asst. for Civil Defense, OSD, Washington 25, D. C.	211
Chairman, Armed Services Explosives Safety Board, D/D, Rm 2403, Barton Hall, Washington 25, D. C.	212
Chairman, Research and Development Board, D/D, Washington 25, D. C. ATTN: Technical Library	213
Executive Secretary, Committee on Atomic Energy, Research and Development Board, Rm 3E1075, Pentagon, Washington 25, D. C.	214-215
Executive Secretary, Military Liaison Committee, PO Box 1814, Washington 25, D. C.	216
Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary	217

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